(12) UK Patent Application (19) GB (11) 2 008 756 A

(21) Application No 7849150
(22) Date of filing 19 Dec 1978
(23) Claims filed 19 Dec 1978
(30) Priority data
(31) 40636/77
(32) 30 Sep 1977
(33) United Kingdom (GB)
(43) Application published 6 Jun 1979
(51) INT CL[2] G01N 29/04
(52) Domestic classification G1G 1A 2 3B 5A1 6 7T PC
(56) Documents cited
GB 1075461
GB 1001857
N "Werkstoffprüfung Mit Ultraschall" J & J Krautkrämer, 3rd Ed., 1975 (Springer) e.g. pp 437, 450, 451 (Equivalent to English 2 nd Ed. 1977) pp 434, 447, 448. N "Electromagnetic Generation of Ultrasonic Surface Waves" by P. Klimo. Journal of Physics E, 1975, Vol. 8 pp 998—9
(58) Field of search G1G
(71) Applicants
TI (Group Services) Limited, TI House, Five Ways, Birmingham, B16 8SQ
(72) Inventors
Donald Wilson
(74) Agents
Barker, Brettell & Duncan

(54) Ultrasonic Inspection of Tubes

(57) Method and apparatus for the ultrasonic inspection of tubes in which ultrasonic waves are generated in the wall of the tube so as to travel in a first helical path 12 along the tube and be reflected by a longitudinal flaw 13 into a second helical path 14, and in which ultrasonic waves travelling in the wall of the tube along the second helical path 14 crossing said first helical path 12 are detected, thereby to discriminate against detection of ultrasonic waves travelling along said first helical path. Preferably, the waves are generated and detected using an electromagnetic-acoustic technique, and the waves are Lamb waves. A preferred form of electromagnetic-acoustic transducer comprises at least two substantially parallel conductors 15 that lie substantially perpendicular to the respective helical path and are spaced apart by substantially a multiple of half a wavelength of the ultrasonic waves along said path. Circumferential flaws may also be detected.

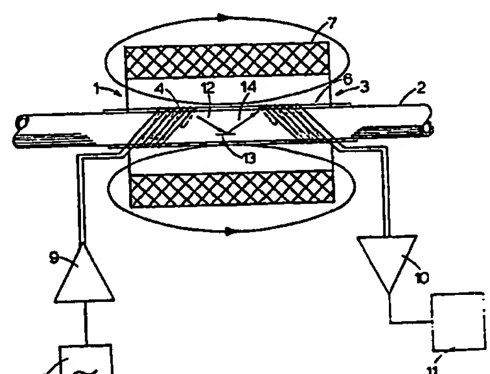

FIG. 1.

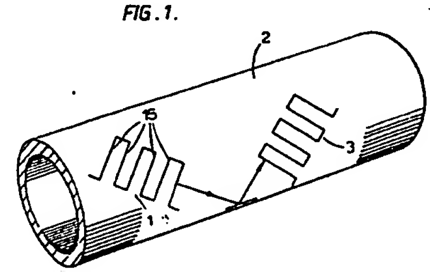

FIG. 4.

GB 2 008 756 A

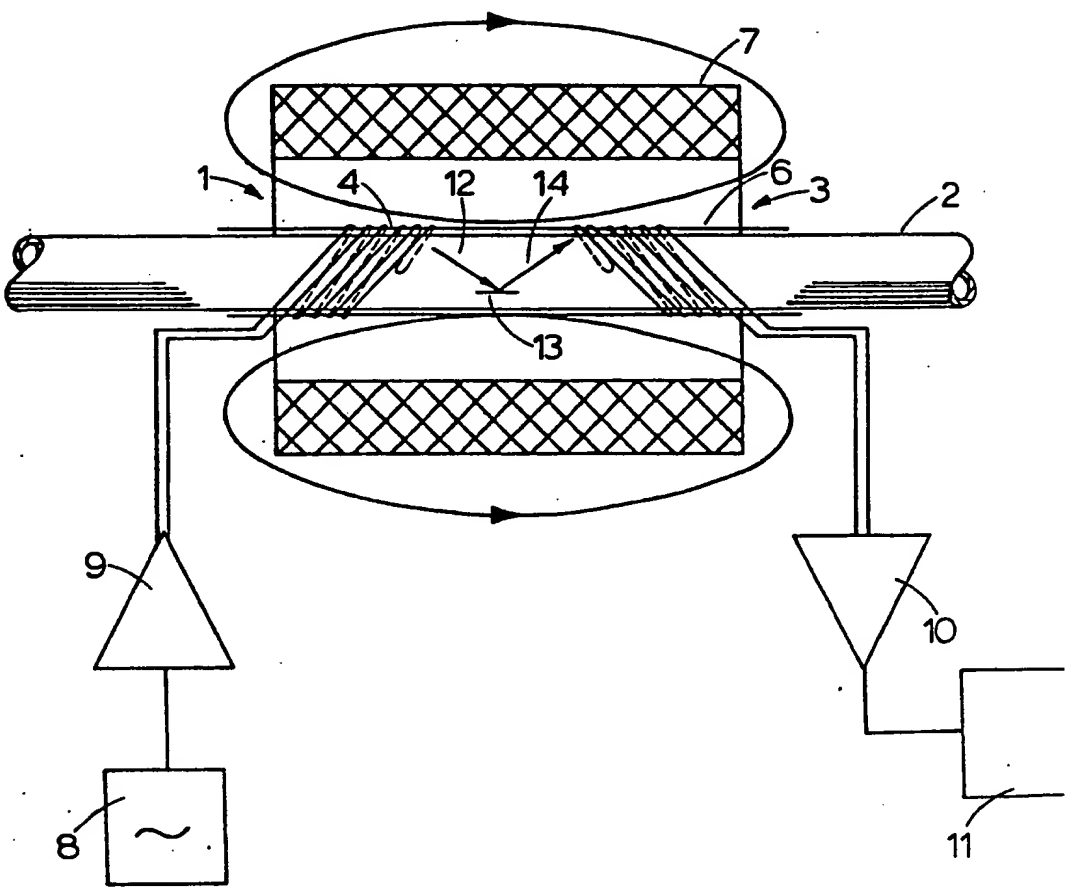

FIG. 1.

2008756 2/3

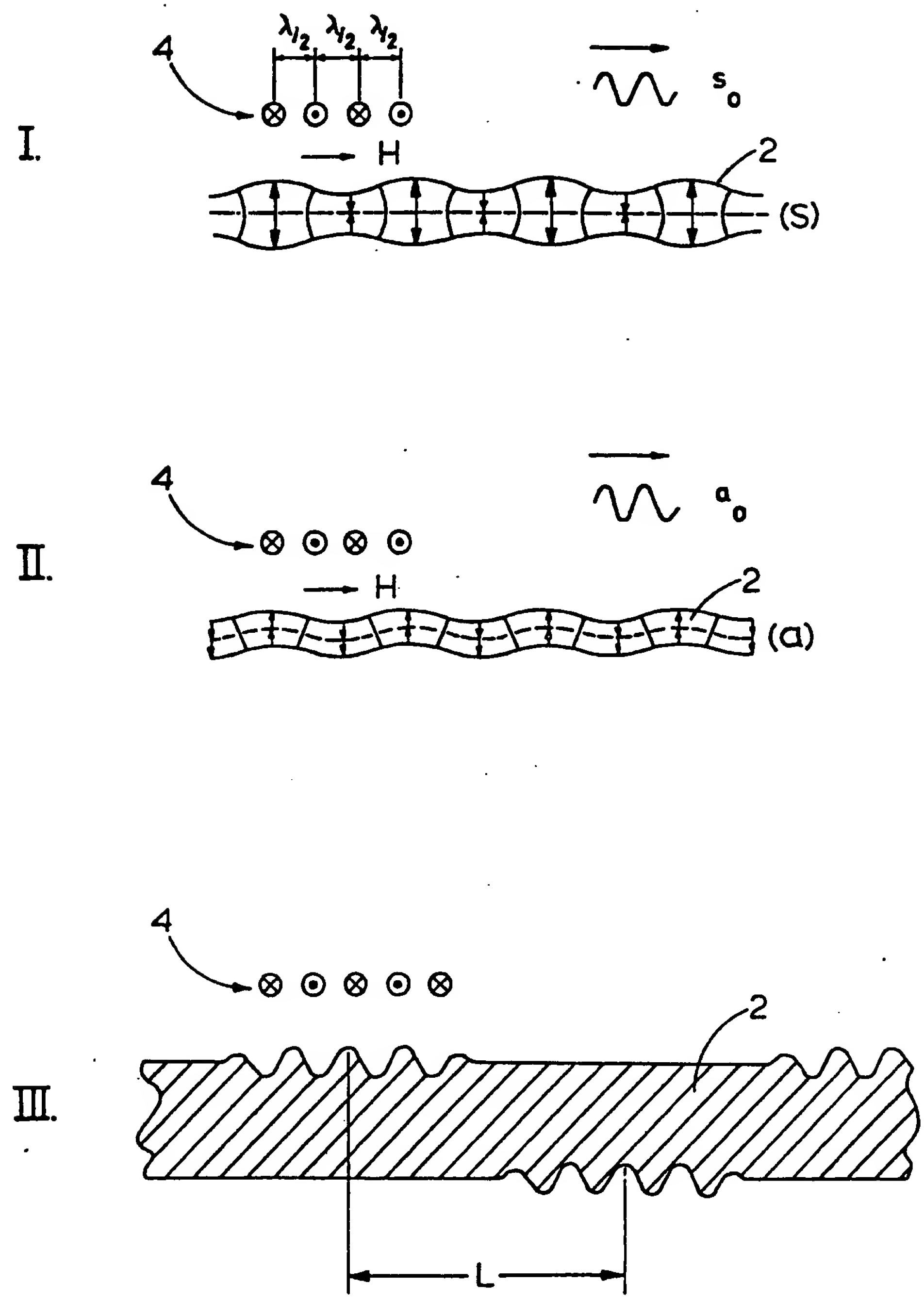

FIG. 2.

2008756

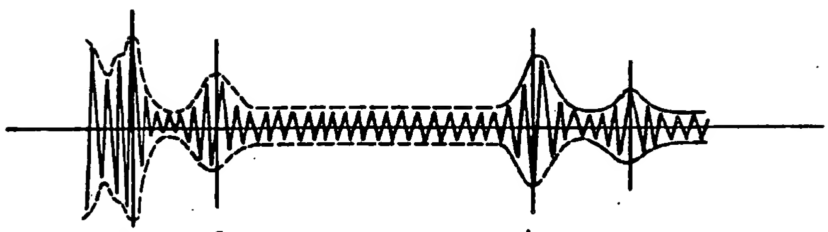

FIG. 3.

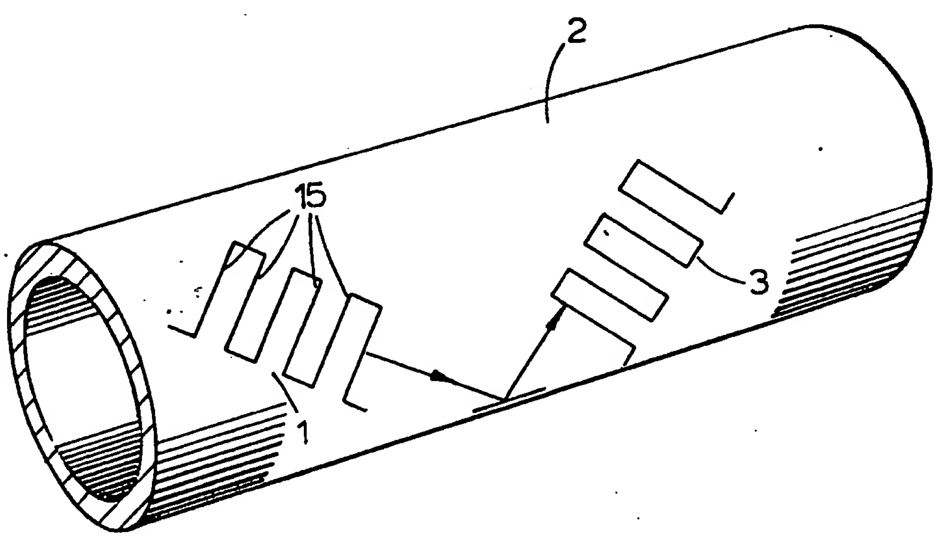

FIG. 4.

SPECIFICATION
Ultrasonic Inspection

This invention relates to the ultrasonic inspection of the walls of tubes.

It is known to test the walls of tubes for flaws by directing a beam of ultrasonic waves into the wall and detecting ultrasonic waves reflected from any flaws therein. It is also known to direct the beam of waves in a helical path along the tube so as to detect flaws at various orientations, but in this inspection system the same water-coupled transducer is used to generate and detect the waves, the detected waves being those that are reflected back along the same helical path as the generated beam. However, waves are only reflected 180° back along the same helical path if they are incident normally on the flaw. This limitation is mitigated by generating a divergent beam so that a different part thereof will be reflected over a range of flaw orientations, but then the detected waves will be of reduced intensity.

The present invention consists in providing an improved method and apparatus for the ultrasonic inspection of tubes in which ultrasonic waves are generated in the wall of the tube so as to travel in a first helical path along the tube, and in which ultrasonic waves travelling in the wall of the tube along a second helical path crossing said first helical path are detected, thereby to discriminate against detection of ultrasonic waves travelling along said first helical path.

Preferably an electromagnetic-acoustic technique is used to generate and detect the ultrasonic waves. This technique can be used with electrically conducting bodies and involves the use of a conductor that is located close to the surface of the body so that a radio frequency current applied to it will induce eddy currents in the body that in turn interact with an applied magnetic field to produce ultrasonic waves. The occurrence of ultrasonic waves beneath the transducer in the presence of an applied magnetic field will also produce eddy currents in the body that in turn induce a current in the conductor indicative of the detection of said ultrasonic waves. Clearly, the advantage of the electromagnetic-acoustic technique is that it does not require contact of the transducer with the body.

Preferably, the waves generated are Lamb waves which involve symmetric and antisymmetric vibrational modes of the whole cross-section of the tube wall at discrete resonant frequencies dependant upon the thickness of the tube wall.

A preferred form of electromagnetic-acoustic transducer comprises at least two substantially parallel conductors that lie substantially perpendicular to the respective helical path and are spaced apart by substantially a multiple of half a wavelength of the ultrasonic waves along said path.

The parallel conductors may comprise three or more conductors with each end of each intermediate conductor connected to the adjacent end of a neighbouring conductor so that the conductors form a continuous current path with the current flow in opposite directions along successive conductors.

Alternatively, there may be two parallel conductors that are helically coiled around the tube and have their respective ends at one end of the coil connected together and their respective ends at the other end of the coil connected to the radio frequency current receiver or current detector.

The invention will now be disclosed by way of example with reference to the accompanying drawings in which:—

Figure 1 is a schematic diagram of ultrasonic tube inspection apparatus according to the invention,

Figure 2 is a schematic diagram showing the form of the ultrasonic waves produced by the apparatus of Figure 1,

Figure 3 is a diagram showing the detected wave signals obtained using the apparatus of Figure 1, and

Figure 4 is a schematic diagram of alternative electromagnetic-acoustic transducers for use according to the invention.

The ultrasonic tube inspection apparatus illustrated in Figure 1 comprises an electromagnetic-acoustic transducer 1 for generating Lamb waves in the wall of a mild steel tube 2, and an electromagnetic-acoustic transducer 3 for detecting Lamb waves in the wall of the tube at a location spaced away from the generating transducer 1. Each transducer 1, 3 comprises a wire conductor 4, 5 wound in a bifilar manner on a thin supporting sleeve 6 so that there is a regular spacing between neighbouring turns of the coil equal to half a wavelength of the Lamb waves. A direct current electromagnet 7 surrounds the tube and both transformers so as to produce a magnetic field H in the tube wall for the generation and detection of the Lamb waves. A variable frequency, variable length pulsed continuous wave generator 8 supplies a radio frequency current to the conductor 4 of the generating transducer 1 via an amplifier 9, and current signals induced in the conductor 5 of the detecting transducer 3 are amplified in an amplifier 10 and control the display on a cathode ray tube display 11.

The generating transducer is preferably used to generate Lamb waves of the lowest order symmetrical mode (s_0) as shown in Figure 2i), because these can travel several meters along the tube wall without suffering significant attenuation. The waves are produced by the Lorenz forces generated in the wall of the tube 2 by the interaction between the magnetic field H and the eddy currents induced in the tube wall by the current flowing in successive turns of conductor 4. The pattern of Lorenz forces produced in the tube wall is indicated by the arrows in Figure 2i), the forces beneath the

successive turns of the conductor 4 being reversed due to the reversal of current flow in successive outward and return flow portions of the bifilar wound conductor.

Typically, when inspecting mild steel tubes of 9.5 m.m. outer diameter and 1 m.m. wall thickness, the Lamb waves are produced at; a frequency of 1.7 MH_z and a wavelength of 3 m.m.

It will be appreciated that the Lamb waves generated will be directed substantially perpendicular to the conductor 4, and if the conductor is wound so that successive turns lie substantially perpendicular to the axis of the tube 2, then the Lamb waves will be directed along the tube substantially parallel to said axis. The waves will not therefore be reflected or modified to any significant extent by longitudinally directed faults in the tube wall. The conductor 4 is therefore wound so that it is inclined at an angle to the axis of the tube and directs waves along a first helical path 12 in the tube wall, as shown in Figure 1, and will be incident at an angle on a longitudinal flaw 13 and will be reflected along a second helical path 14.

The conductor 5 of the detecting transducer 3 is similarly wound so that it is inclined to the axis of the tube, but conductor 5 is inclined in the opposite sense to conductor 4 so as to lie perpendicular to the second helical path 14 for reflected waves. Conductor 5 therefore detects reflected waves travelling along said second helical path 14, the waves interacting with the magnetic field H of magnet 7 to generate eddy currents that induce corresponding currents in conductor 5.

Preferably, conductor 4 is inclined at an angle of 45° to the tube axis so as to direct waves along said first helical path, and the conductor 5 is inclined in the opposite sense at an angle of 45° to the tube axis so as to be normal to waves travelling along said second helical path that crosses said first helical path perpendicularly. The two transducers are therefore arranged with their respective generating and detecting paths mutually perpendicular to one another so that the detecting transducer 3 will not detect waves transmitted directly from the generating transducer 1, but will only detect waves that have been reflected from their original path, for example, by faults, which may be either longitudinal or circumferential faults, the waves being reflected through 90° in both cases.

An example of the use of the apparatus in detecting a flaw in the wall of a mild steel tube is shown in Figure 3. The tube has an outer diameter of 9.5 m.m. and has a wall 1 m.m. thick. The flaw is a 0.125 m.m deep longitudinal notch in the tube wall and is located between the two transducers 1 and 3. The waves used are 1.7 MH_z Lamb waves in the s_0 mode with a wavelength of 3 m.m. Figure 3 shows the trace produced on the cathode ray tube display 11. Because of electromagnetic coupling between the two transducers, pulsing of the generating transducer 1 produces the pulse *a* in the detecting transducer 3. Pulse *f* is the reflection from the flaw, and pulses *b* and *c* are reflections from the ends of the tube.

In the above example, the two transducers 1 and 3 are used to detect a longitudinal flaw therebetween. However, they can also be used to detect circumferential faults lying on either side of the two transducers 1 and 3, such faults causing reflection of the waves back along the tube towards the transducers, as shown for flaw 13′ in Figure 1.

The reflected waves from longitudinal flaws between the transducers and the reflected waves from circumferential flaws on either side of the two transducers, travel beneath the detecting transducer 3 in opposite directions, and this allows the two types of flaws to be distinguished one from the other. The direction of travel of the waves can be determined by providing two spaced apart detecting transducers 3 to detect waves travelling along the same helical path, the order in which they detect the waves indicating their direction of travel. The two transducers 3 may be spaced apart sufficiently for there to be a gap between them or only slightly so that they overlap one another

Where the electromagnets are widely spaced apart, separate electromagnets can be used instead of the one common electromagnet 7.

The current flowing in the electromagnet is controlled so that the magnetic field intensity is kept within an optimum range about a peak in the graph of Lamb wave intensity against magnetic field intensity.

Beyond this peak, an increase in the magnetic field intensity causes the intensity of the Lamb waves to fall.

The invention is not restricted to the use of Lamb waves in the lowest order symmetrical mode s_0, but can be used with Lamb waves in the lowest order asymmetrical mode a_0, illustrated in Figure 2ii), and with the higher modes. It is necessary to use the highest modes in inspecting tubes with thicker walls, for example, walls thicker than 5 m.m., but these higher modes are more difficult to generate due to reduced coupling between the transducer and the tube walls, and they are more greatly attenuated. For these reasons it is preferred to use so-called quasi-Rayleigh waves to inspect thicker walled tubes

Quasi-Rayleigh waves are produced by interference between the s_0 and a_0 modes. At the transmitting transducer these modes are in phase and produce constructive interference at one surface and destructive interference at the opposite surface so that the resulting wave resembles a surface wave, i.e. a Rayleigh wave. However, because the two modes s_0 and a_0 have different group velocities, the phase difference between them changes during propagation and at intervals L, dependent upon wall thickness, when the phase difference has changed by π, the resulting wave transverses from one surface to the other as shown in Figure 2iii).

In yet other embodiments of the invention, the

bifilar wound conductors can be replaced by conductors of the form illustrated in Figure 4 comprising a plurality of parallel conductor portions 15 with the opposite end of each intermediate portion 15 connected to the adjacent ends of a neighbouring portion 15 so as to form a continuous current path with the current flow in opposite directions along successive conductor portions 15. The portions 15 are therefore the equivalent of the successive turns of the bifilar wound conductors and are likewise spaced half a wavelength apart.

The conductor portions 15 may be formed from a single wire conductor or may be etched from a printed circuit board.

It will be appreciated that the radio frequency current flowing in the conductor of the generating transducer produces its own magnetic field which interacts with the eddy currents induced in the surface of the body to produce Lorenz forces therein. However, because the alternating magnetic field is always in phase with the eddy currents, the Lorenz forces produced are always uni-directional and the resulting waves have a wavelength equal to the spacing of the turns or parallel portions of the conductors, that is half a wavelength of the waves generated by virtue of the steady magnetic field H applied to the same transducer.

This effect is made use of in another embodiment of the invention which lacks the magnet for the generating transducer and in which the turns or parallel portions are spaced apart by substantially a wavelength of the waves to be generated. In this case the current in successive conductors flows in the same direction, so that if the conductor is coiled a single wound coil is used rather than a bifilar wound coil.

The invention has been described above with reference to transducers having conductors with turns or parallel portions of half wavelength and a whole wavelength spacing. However, it will be appreciated that the invention includes transducers in which the half wavelength spacing is changed to a spacing of any odd multiple of half wavelengths, and transducers in which the single wavelength spacing is changed to a spacing of any multiple of whole wavelengths. The efficiency of these alternative transducers may be reduced as compared with the half wavelength and whole wavelength spacing transducers, but they may offer other advantages such as avoidance of destructive interference between successive parallel conductors due to their being spaced away from the surface of the electrically conducting body.

Claims

1. An ultrasonic method of inspecting a tube comprising generating ultrasonic waves in the wall of the tube so that they travel in a first helical path along the tube, and detecting ultrasonic waves travelling in the wall of the tube along a second helical path that crosses said first helical path, thereby to discriminate against detection of ultrasonic waves travelling along said first helical path.

2. A method as claimed in claim 1 in which said first and second helical paths cross substantially at right angles to one another.

3. A method as claimed in claim 2 in which said first and second helical paths are both inclined at an angle of substantially 45° to lines parallel to the longitudinal axis of the tube.

4. A method as claimed in any one of claims 1 to 3 in which the ultrasonic waves are generated and detected by employing electro-magnetic acoustic techniques.

5. A method as claimed in claim 4 in which the ultrasonic waves are Lamb waves.

6. A method as claimed in claim 4 in which the ultrasonic waves are quasi-Rayleigh waves.

7. A method as claimed in any one of claims 4 to 6 in which the ultrasonic waves are generated by a transducer comprising at least two substantially parallel conductors that are arranged to close to, and electrically insulated from. a surface of the tube, and are connected to a radio frequency current supply, the conductors all lying substantially perpendicular to said first helical path and being spaced apart by substantially a multiple of half a wavelength of the ultrasonic waves along said path.

8. A method as claimed in claim 7 in which a steady magnetic field is applied to the surface of the tube adjacent the transducer, and in which successive conductors are spaced apart by substantially half a wavelength and carry the same radio frequency current in opposite directions.

9. A method as claimed in claim 7 or 8 in which the parallel conductors comprise three or more conductors with each end of each intermediate conductor connected to the adjacent end of a neighbouring conductor so that the conductors form a continuous current path with the current flowing in opposite directions along successive conductors.

10. A method as claimed in claims 7 or 8 in which each conductor is helically coiled around the tube.

11 A method as claimed in claim 10 in which there are two parallel conductors that are helically coiled and have their respective ends at one end of the coil connected together and their respective ends at the other end of the coil connected to the r.f. current supply.

12. A method as claimed in any one of claims 4 to 11 in which the ultrasonic waves are detected by a transducer comprising at least two substantially parallel conductors that are arranged close to, and electrically insulated from, a surface of the tube, to which a steady magnetic field is applied so that the waves produce eddy currents in the tube wall which in turn induce a current in the conductors, the conductors all lying substantially perpendicular to said second helical path and being spaced apart by substantially a multiple of half a wavelength of the ultrasonic waves along said path.

13. A method as claimed in claim 12 in which successive conductors of the detecting transducer are spaced apart by half a wavelength and carry the same detected current in opposite directions.

14. A method as claimed in claim 13 in which the parallel conductors of the detecting transducer comprise three or more conductors with each end of each intermediate conductor connected to the adjacent end of a neighbouring conductor so that the conductors form a continuous current path with the detected current flowing in opposite directions along successive conductors.

15. A method as claimed in claim 12 or 13 in which each conductor of the detecting transducer is helically coiled around the tube

16. A method as claimed in claim 15 in which the detecting transducer comprises two conductors that are helically coiled and have their respective ends at one end of the coil connected together and their respective ends at the other end of the coil connected to a current detector.

17. A method as claimed in any one of the preceding claims in which the direction of travel of the waves along said second helical path is determined by detecting the waves at two spaced apart points along said path and comparing the timing of wave detection at the two points.

18. Ultrasonic apparatus for inspecting tubes comprising an ultrasonic wave generator and an ultrasonic wave detector, both being adapted to be located in relation to the surface of a tube so as to generate and detect waves in the tube wall. respectively, and the generator further being adapted to generate waves that travel along a first helical path along the tube, and the detector further being adapted to detect waves that travel along a second helical path along the tube crossing said first helical path, thereby to discriminate against detection of waves travelling along said first helical path.

19. Ultrasonic apparatus as claimed in claim 18 in which the generator and detector both comprise electromagnetic-acoustic transducer.

20. Ultrasonic apparatus as claimed in claim 19 in which the transducer of the generator comprises at least two substantially parallel conductors that are to be arranged close to and electrically insulated from. a surface of the tube, and are connected to a radio frequency current supply, the conductors all lying substantially perpendicular to said first helical path and being spaced apart by substantially a multiple of half a wavelength of the waves along said path.

21. Ultrasonic apparatus as claimed in claim 20 in which the generator includes a magnet that applies a steady magnetic field to the surface of the tube adjacent the parallel conductors, successive conductors being spaced apart by substantially half a wavelength and carrying the same radio frequency current in opposite directions.

22. Ultrasonic apparatus as claimed in any one of claims 19 to 21 in which the transducer of the detector comprises at least two substantially parallel conductors that are to be arranged close to and electrically insulated from a surface of the tube, and lie substantially perpendicular to said second helical paths and are spaced apart by substantially a multiple of half a wavelength of waves along said path, and further comprises a magnet that applies a steady magnetic field to the surface of the tube adjacent the conductors, and a radio frequency current detector connected to said conductors.

23. Ultrasonic apparatus as claimed in claim 22 in which successive conductors of the transducer of the detector are spaced apart by half a wavelength and carry the same detected current in opposite directions.

24. Ultrasonic apparatus as claimed in any one of claims 18 to 23 in which the parallel conductors comprise three or more conductors with each end of each intermediate conductor connected to the adjacent end of a neighbouring conductor so that the conductors form a continuous current path with the current flowing in opposite directions along successive conductors.

25. Ultrasonic apparatus as claimed in any one of claims 20 to 23 in which each conductor is helically coiled around the tube.

26. Ultrasonic apparatus as claimed in claim 25 in which there are two parallel conductors that are helically coiled and have their respective ends at one end of the coil connected together and their respective ends at the other end of the coil connected to the current supply or current detector.

27. Ultrasonic apparatus as claimed in any one of claims 18 to 26 in which two ultrasonic wave detectors are provided at spaced apart points along said second helical path to determine the direction of travel of waves along said path, comparator means being provided to compare the timing of wave detection at the two points.

28. An ultrasonic method of inspecting a tube substantially as herein described with reference to the accompanying drawings.

29. Ultrasonic apparatus for inspecting a tube substantially as herein described with reference to the accompanying drawings.

Printed for Her Majesty's Stationery Office by the Courier Press, Leamington Spa 1979. Published by the Patent Office, 25 Southampton Buildings London WC2A 1AY, from which copies may be obtained.